Coordinated Observations of Optical Lightning from Space Using the FORTE/OLS Photodiode Detector And CCD Imager

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ABSTRACT

The Fast On-Orbit Recording of Transient Events (FORTE) satellite is a joint Los Alamos National Laboratory and Sandia National Laboratories experiment that was launched into a nearly circular low-earth orbit on Aug. 29, 1997. The payload consists of broadband VHF receivers and a two-sensor Optical Lightning System (OLS). The OLS is comprised of a broadband (400 - 1100 nm) silicon photodiode detector (PDD) that collects 1.92 ms records of lightning transients with a 15 us time resolution, and a narrow-band (777.6 nm ± 0.5 nm) 128 x 128 pixel CCD array called the Lightning Location System (LLS) that provides imaging and geolocation of these events to within a pixel size of 10 km x 10 km. Together, the two sensors provide a high-resolution spatial and temporal description of detected lightning events.

This paper presents an overview of the coordinated observation of optical lightning from space using the FORTE/OLS PDD and LLS detectors. PDD/LLS coincidence statistics are presented and indicate that better than 20 % of the LLS-detected events are in temporal and spatial coincidence with PDD triggers. The requirement of coincident PDD/LLS detection of lightning events is used to help discriminate against false LLS events due to energetic particles and glint. Recurrence/clustering filters based on these coincidences are used to associate additional non-coincident PDD and LLS events with established storm activity. Energy density measurements of coincident events show that about 10 % of the optical energy detected by the broadband PDD appears in the narrowband LLS. This is in good agreement with ground-based measurements and with assumptions incorporated into the design of the FORTE/LLS and TRMM/LIS imaging sensors. Measured event energy densities also show a strong proportionality to the number of pixels activated in an LLS event. Properties of the coincident LLS and PDD data set are also analyzed as a function of lightning type (CG versus IC) by way of comparisons with ground-based National Lightning Detection Network (NLDN) data and the Kennedy Space Center Lightning Detection and Ranging (LDAR) data set.

Motivation for Study

This poster describes the phenomenology and analysis of optical lightning events that were simultaneously observed with both the photodiode detector (PDD) and Lightning Location System (LLS) CCD imager aboard the Fast On-Orbit Recording of Transient Events (FORTE) satellite. The high temporal resolution of the PDD (~15 μs) and the high spatial resolution of the LLS imager (~10 km) combine to give a detailed satellite-based picture of both the spatial and temporal evolution of terrestrial lightning at both the stroke and flash level.

Study Goals

1.) Present basic phenomenology associated with the joint detection of optical lightning by a space-based photodiode (PDD) and CCD imager (LLS).

2.) Explore the relationship between optical waveform features and light scattering.

3.) Demonstrate the use of combined waveform/imager data to improve upon current satellite-based lightning data interpretation and discrimination techniques.

FORTE/OLS Instrument Specifications

PhotoDiode Detector (PDD):

Type:	Single-element silicon photodiode
Size:	1 cm^2
Field-of-view:	~1200 km dia. (80 deg.)
Spectral Response:	0.4 - 1.1 μm
Responsivity:	0.489 A/W @ 0.9 μm (0.3325 A/W avg.)
Sample Rate:	67 kHz (15 μs resolution)
Record Length:	1.92 ms (6.75 ms in LLS slave mode)
Dead Time (between records):	2.5 - 3 ms (2.4 ms in LLS slave mode)

Trigger modes:

- Autonomous, threshold triggered
- Slaved to LLS
- Slaved to VHF receiver

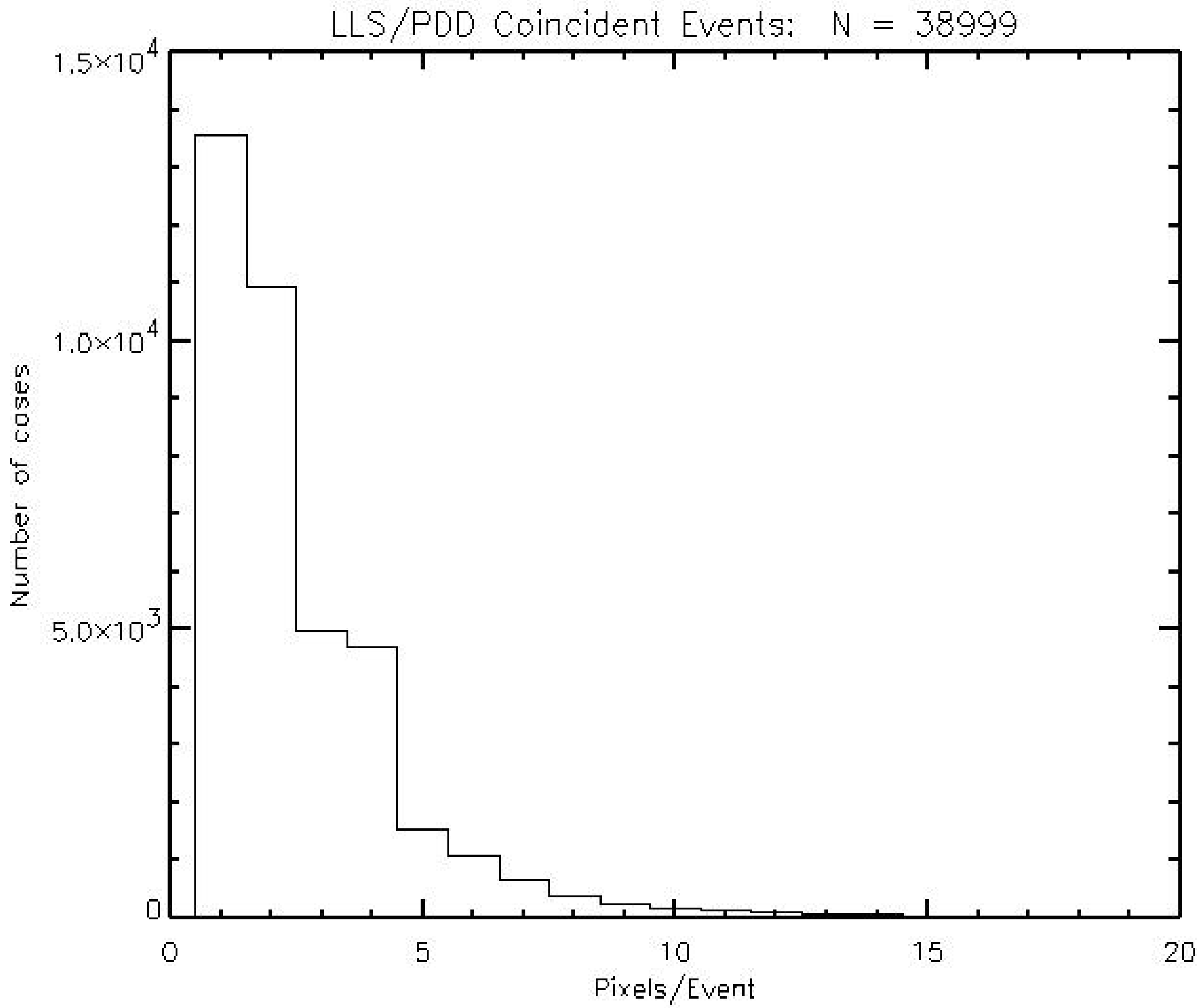
FORTE/OLS Instrument Specifications

Lightning Location Sensor (LLS):

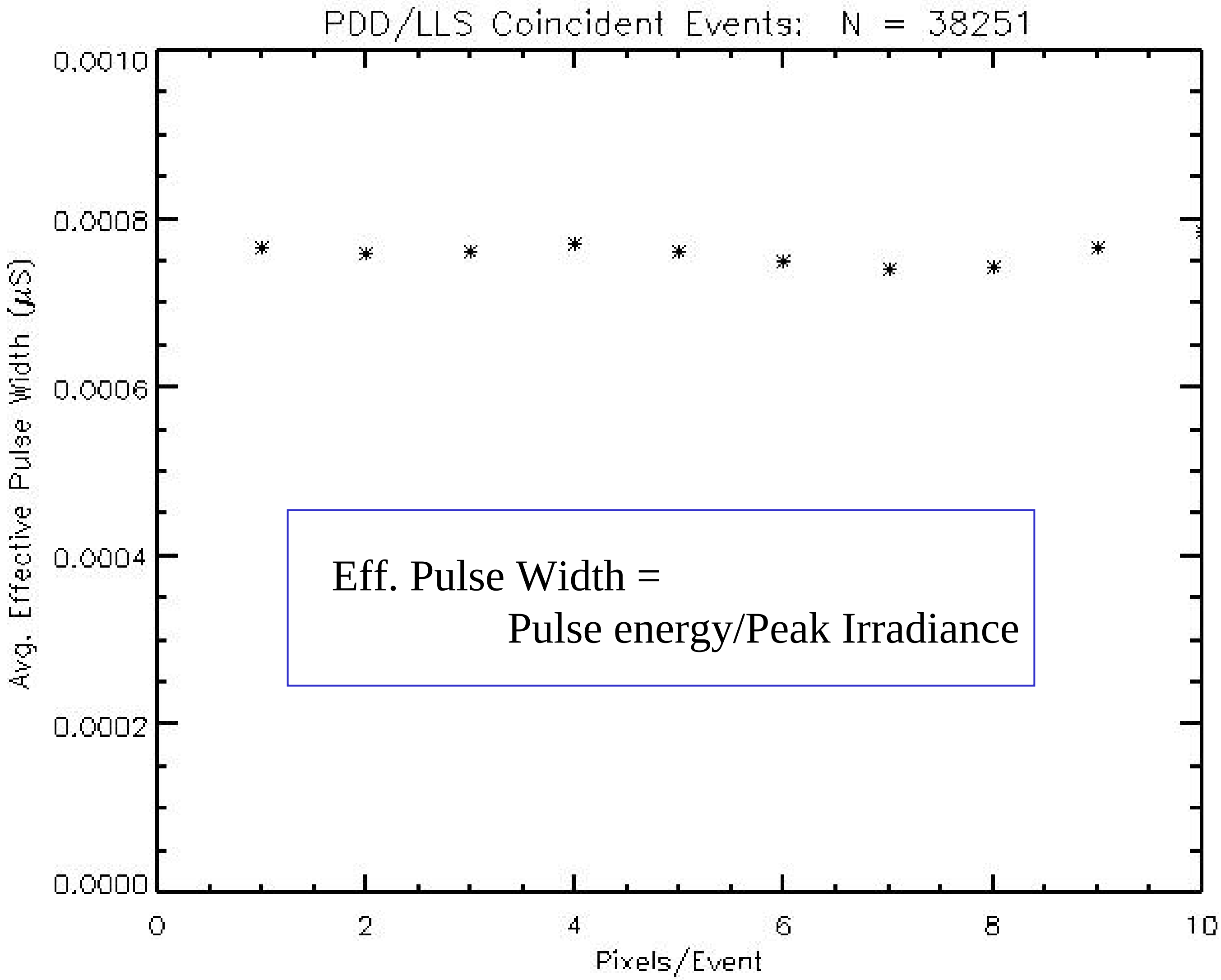
Type:	CCD array
Effective Array Size:	128 x 128 pixels
Field-of-view:	~1200 km dia. (80 deg.)
Spectral Response:	0.1 nm FWHM filter (centered on 777.4 nm)
Geolocation accuracy:	1-2 pixels (1 pixel ~ 10 km x 10 km)
Integration Time:	2.4 ms
Anti-glint feature:	If any pixel lights up for more than 2 consec. sample periods, entire event is ignored
Operating Modes:	• Pixel event mode, threshold trig. • Full frame (imaging) mode • Background mode

Basic Statistics

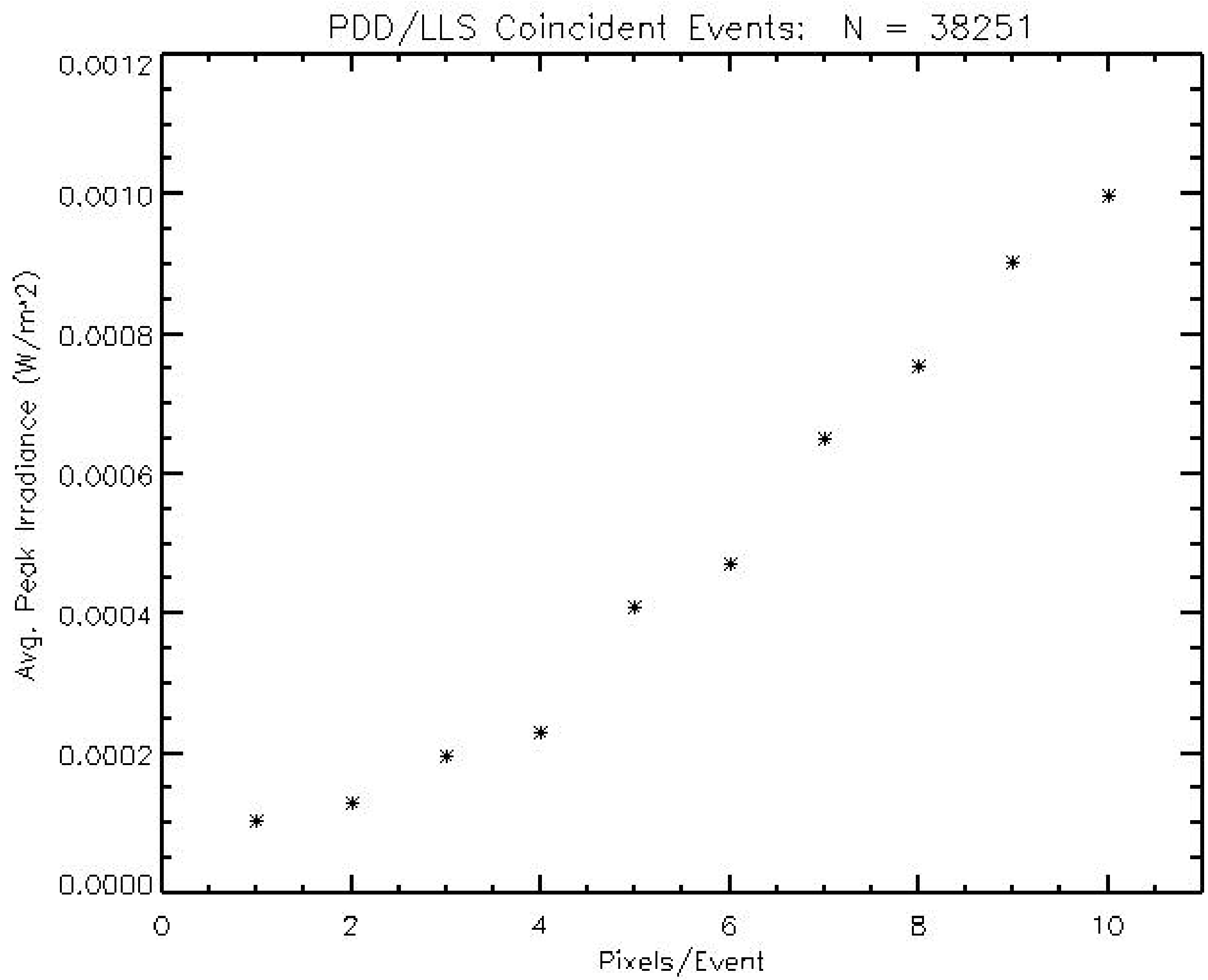
Study Data Set: 38999 lightning events simultaneously detected by both the PDD and LLS from Oct. 1, 1998 to Mar. 1, 1999.



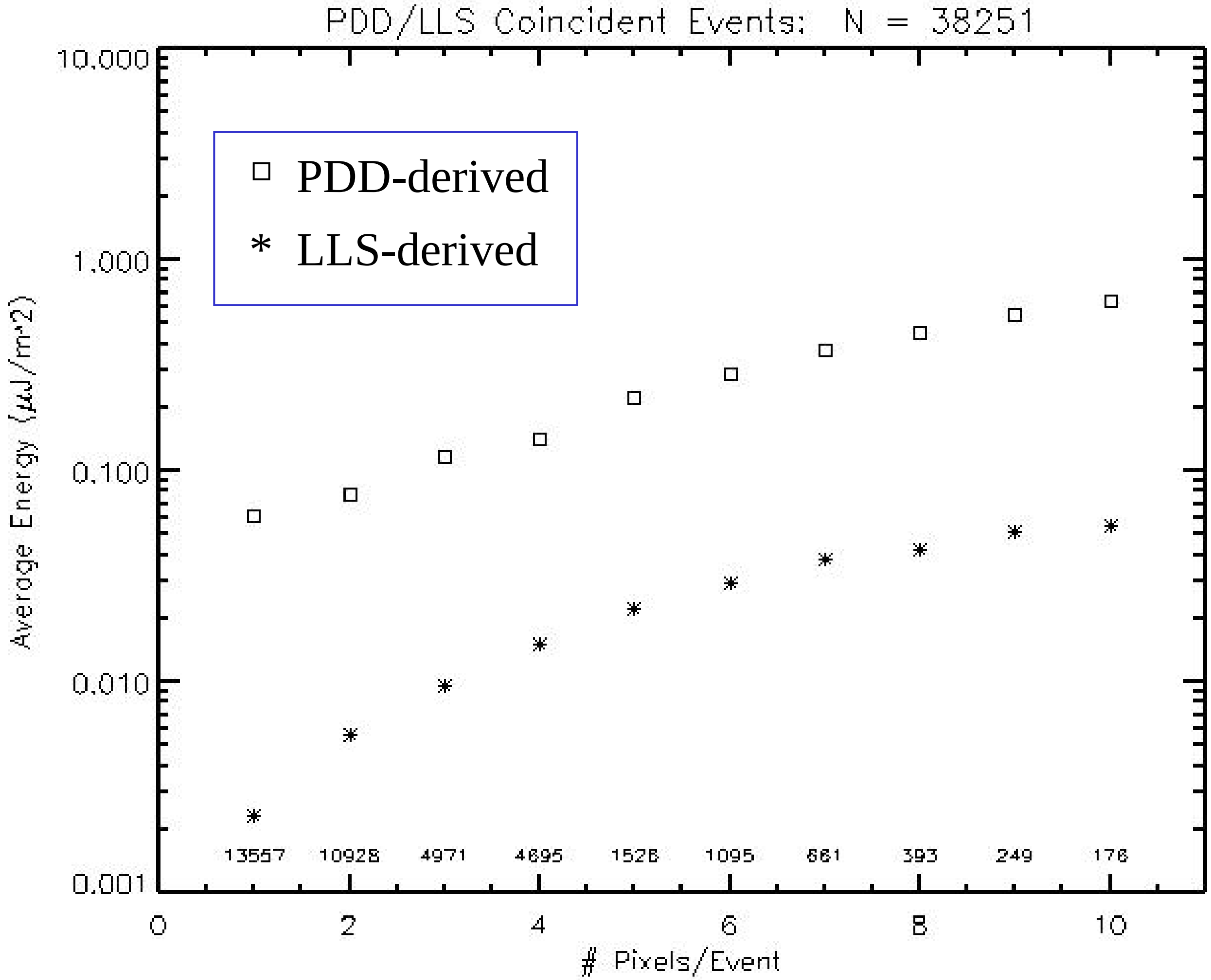
About 35% of coincident LLS/PDD events are 1-pixel events. Over 97% of the events are comprised of 10 or fewer pixels.



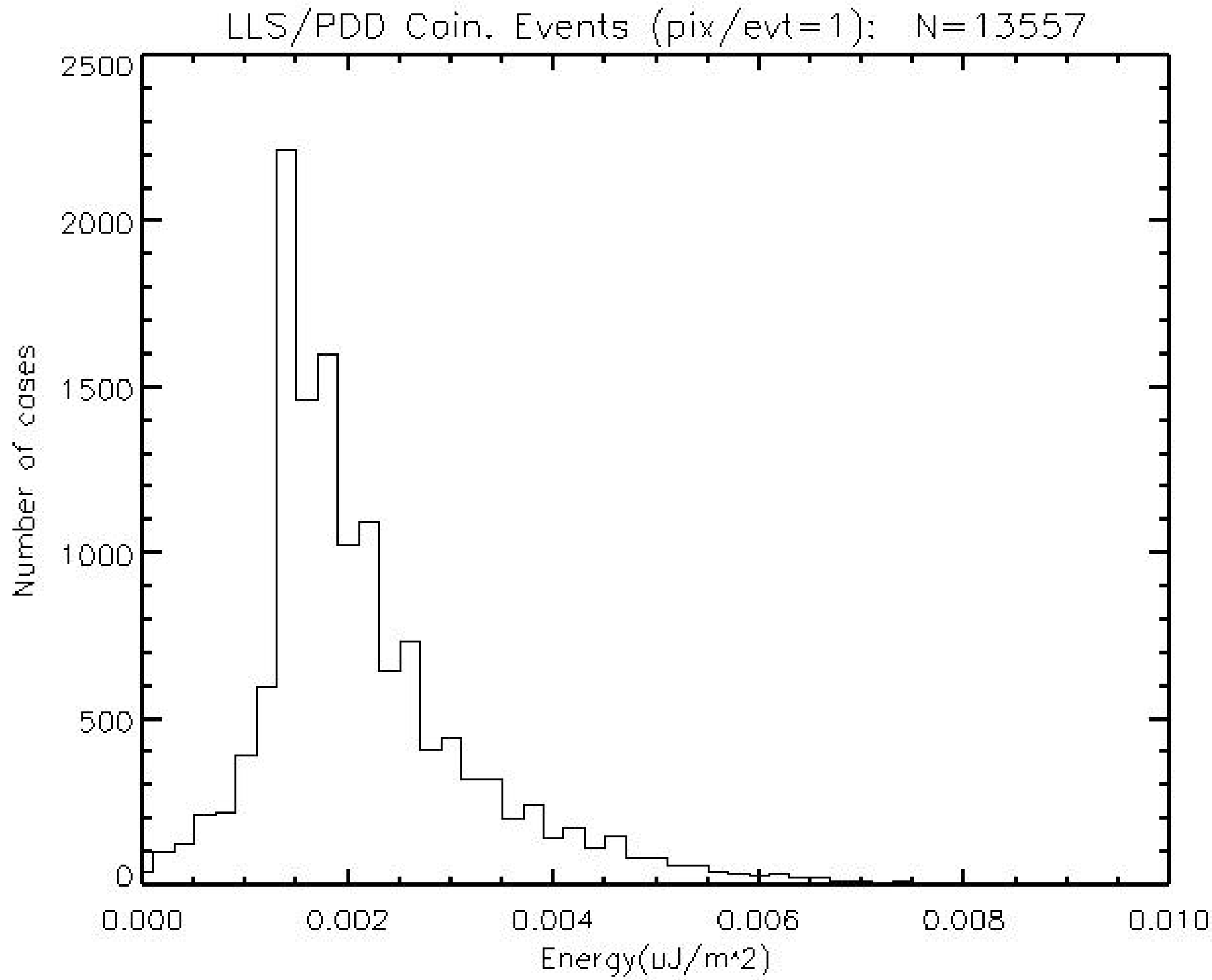
The average effective pulse widths of the PDD waveforms are independent of the number of pixels/event.



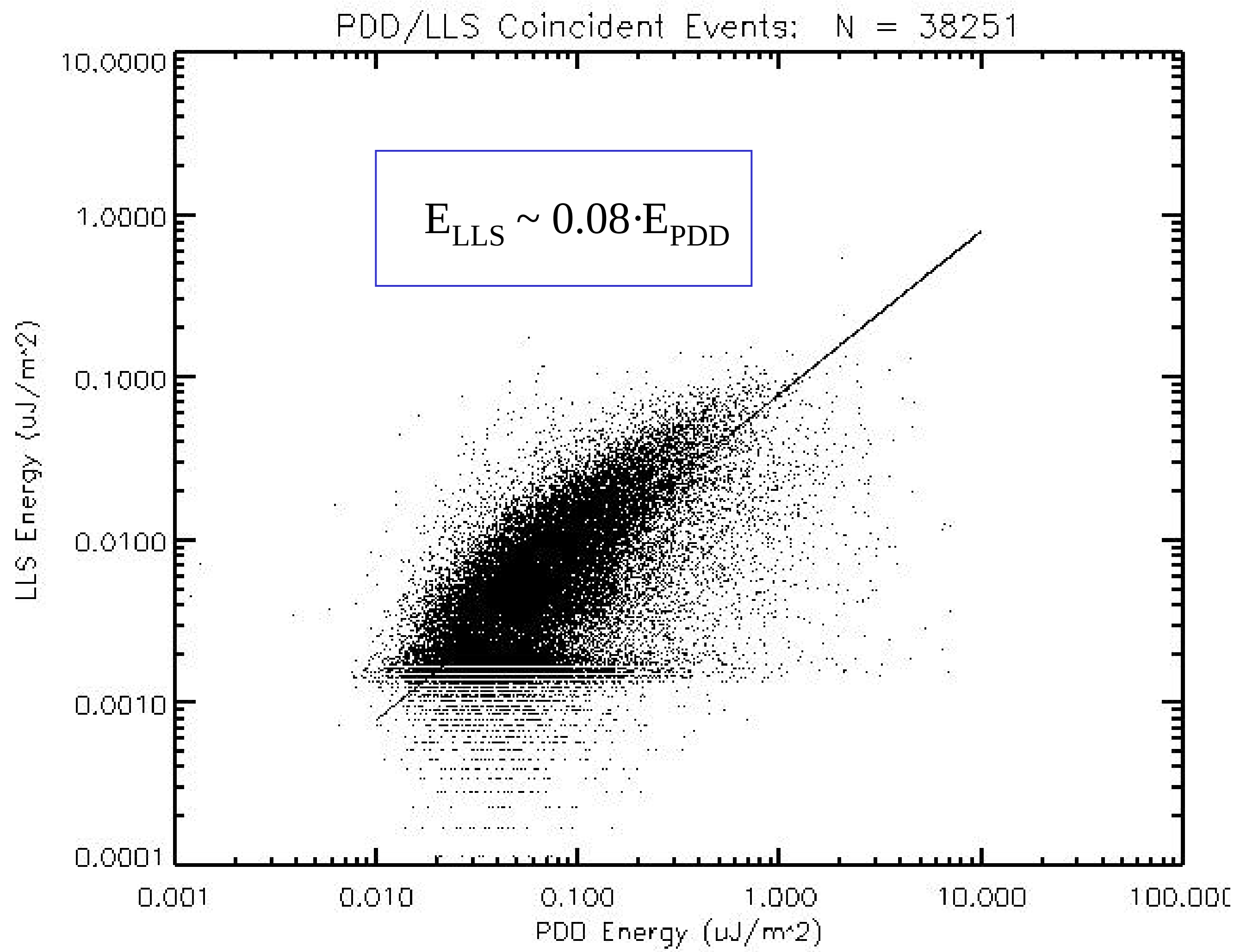
The average peak irradiance of the PDD waveforms increases with an increase in the number of pixels per event.



LLS-derived and PDD-derived average energy densities increase with the number of pixels per event. A basic question is whether this dependence is driven by scattering, by the areal extent of the source function, or some combination of both. This issue is currently being addressed via data analysis and cloud modeling (see the poster by Light et al., A12B-05).



The energy density histogram for the 1-pixel/event data in the graph above is well-behaved, as are those for the > 1-pixel/event data. This indicates that the trend in the previous graph is real and not a result of pixel saturation.



About 8% of the energy detected in the broad-band PDD is seen in the narrow-band LLS. This compares to an expected value of about 1% as inferred from the limited ground-based experimental data reported in Orville & Henderson (1984). This discrepancy is currently unexplained, although the Orville & Henderson (1984) data was collected exclusively from CG return strokes while the PDD and LLS data is dominated by in-cloud events.

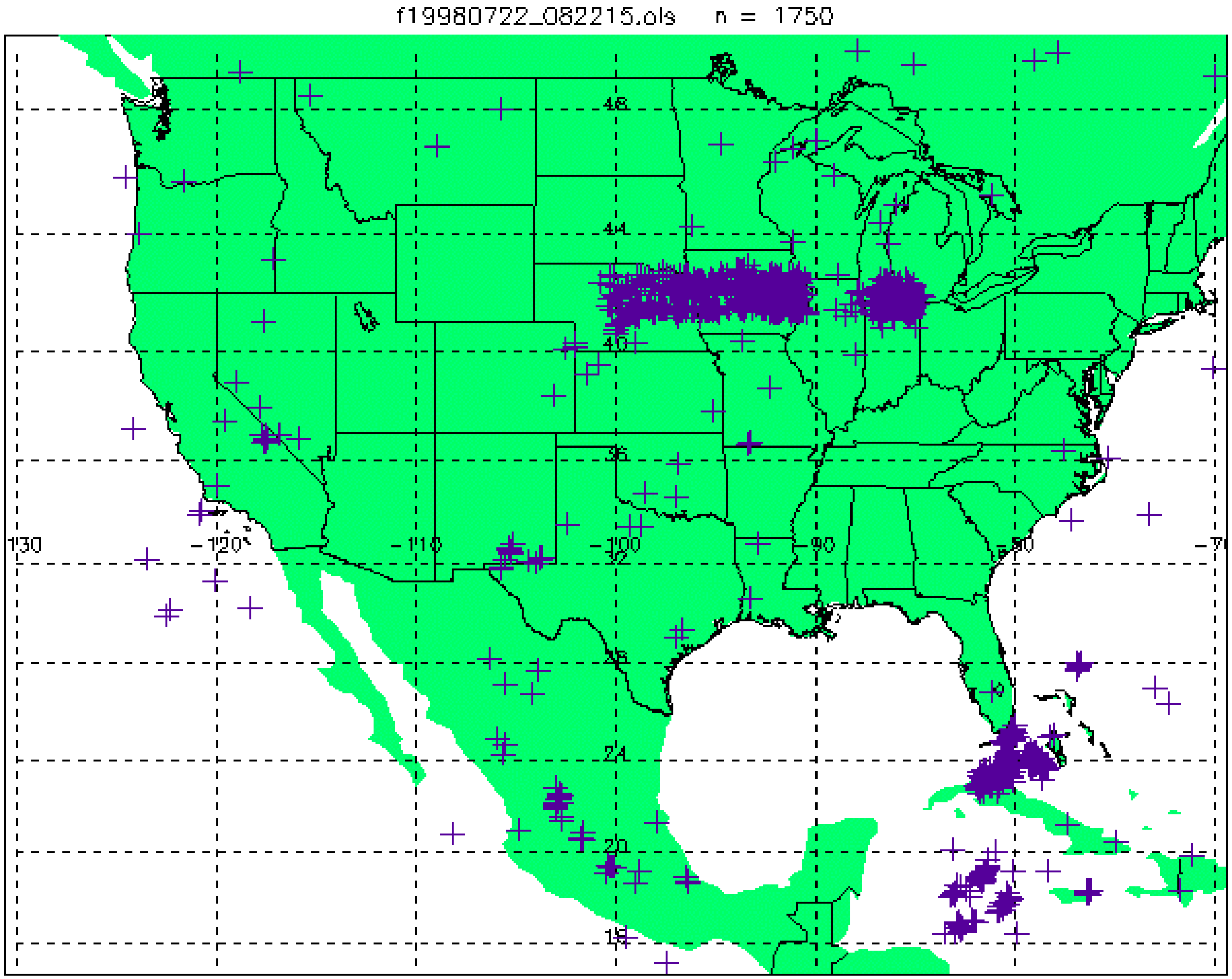
Discrimination Techniques

The majority of LLS triggers are generated by energetic particles and glint rather than by optical lightning events. Many techniques are employed to distinguish between these unwanted triggers and valid lightning events.

Five basic data discrimination filters are employed in the following order:

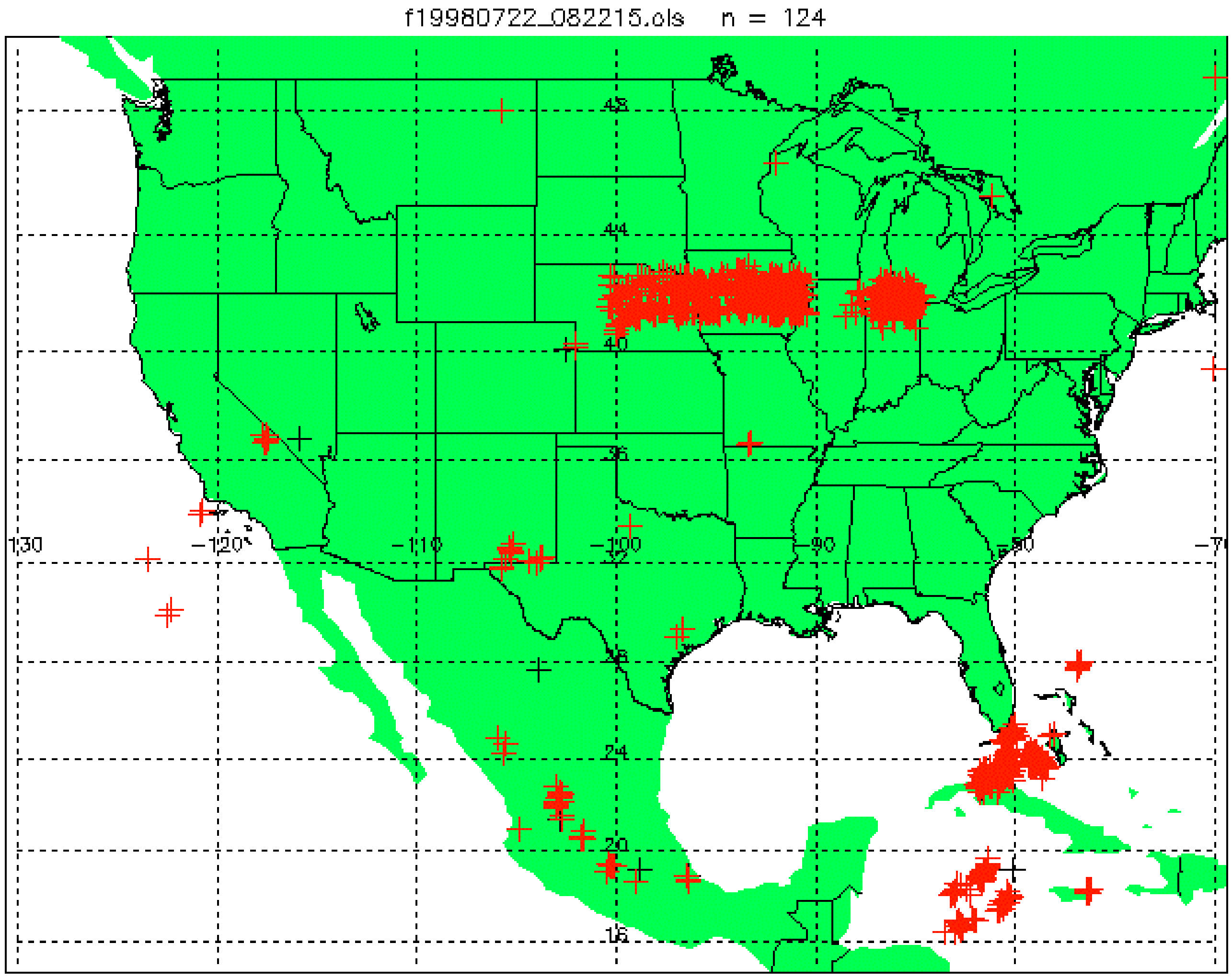
1.) A Disabled Pixel Filter removes events that fall on disabled pixels (damaged pixels or pixels that are obscured by spacecraft hardware (e.g. the VHF antenna, separation ring)).
2.) A Glint/Saturation Filter removes events that contain saturated pixels (amplitudes exceeding 3700 out of a possible 4096 amplitude units). These events are almost exclusively the result of unwanted glint.
3.) A Ghost Pixel Filter removes events that saturate and produce event ghosts in adjacent array quadrants.
4.) Recurrence Filters are used to remove isolated particle events. A typical recurrence filter will keep only those LLS events that lie within x kms and t seconds of each other. This "clustering" of the data was first utilized by NASA/MSFC in the OTD/LIS projects and relies on the fact that valid lightning events will generally occur clustered in time and space. Typical values are t ~ 3 minutes (max. pass time) and x ~ 100 km although actual values are optimized and depend on energetic particle fluxes and storm characteristics (flash rate, areal extent, etc).
5.) A Coincidence Filter requires that an event be detected by both the PDD and LLS. Since the PDD cannot be triggered by an energetic particle, this coincidence requirement along with a check of the PDD waveform assures us that an event is truly a lightning event.

Various versions and combinations of the recurrence and coincidence filters are employed on a case by case basis. Two examples are shown below:

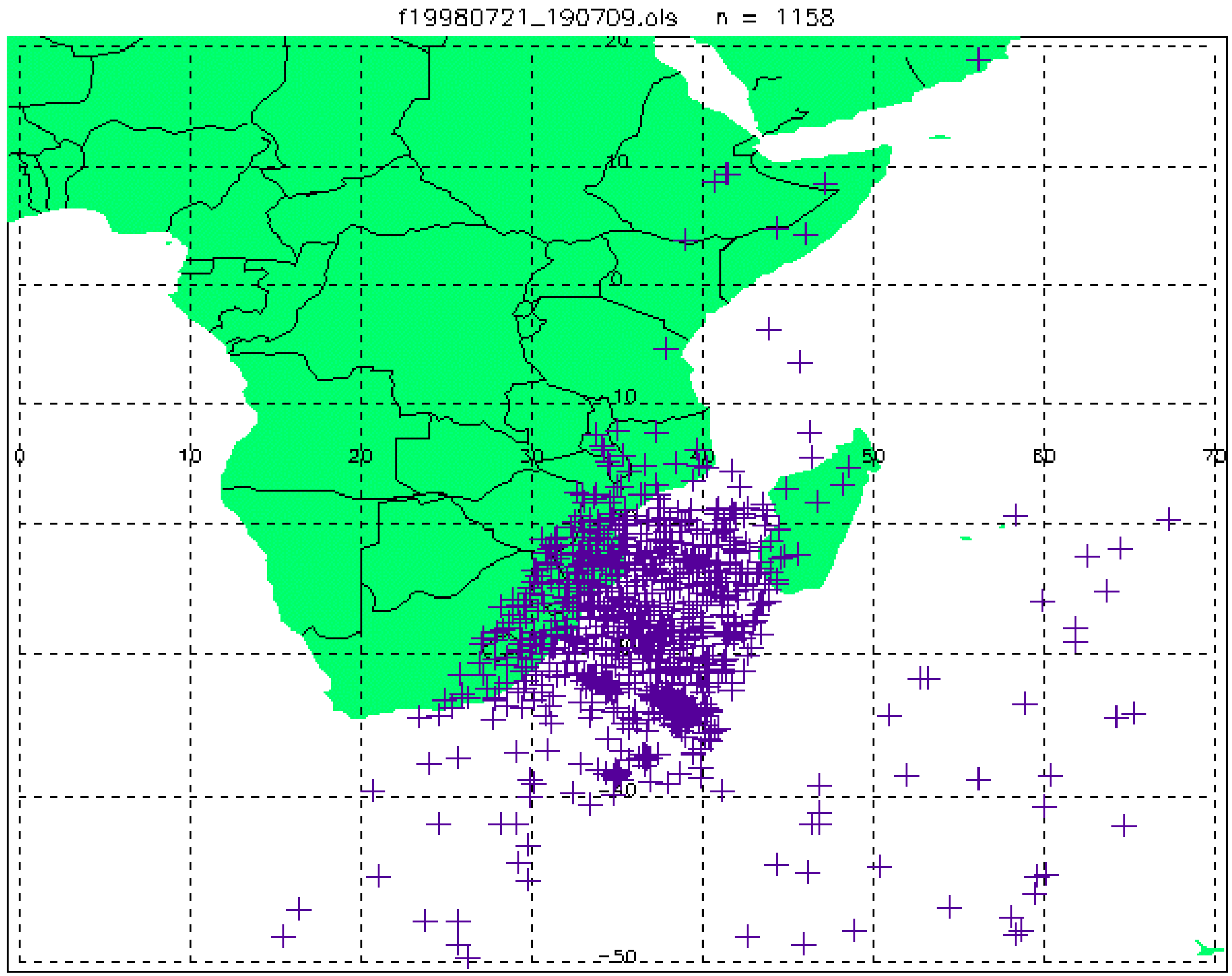


Example 1.

LLS events (purple) prior to application of recurrence filter. Note the storm-localized clustering of likely lightning events that are surrounded by a sparse collection of isolated events, many of which are probably due to random energetic particles.

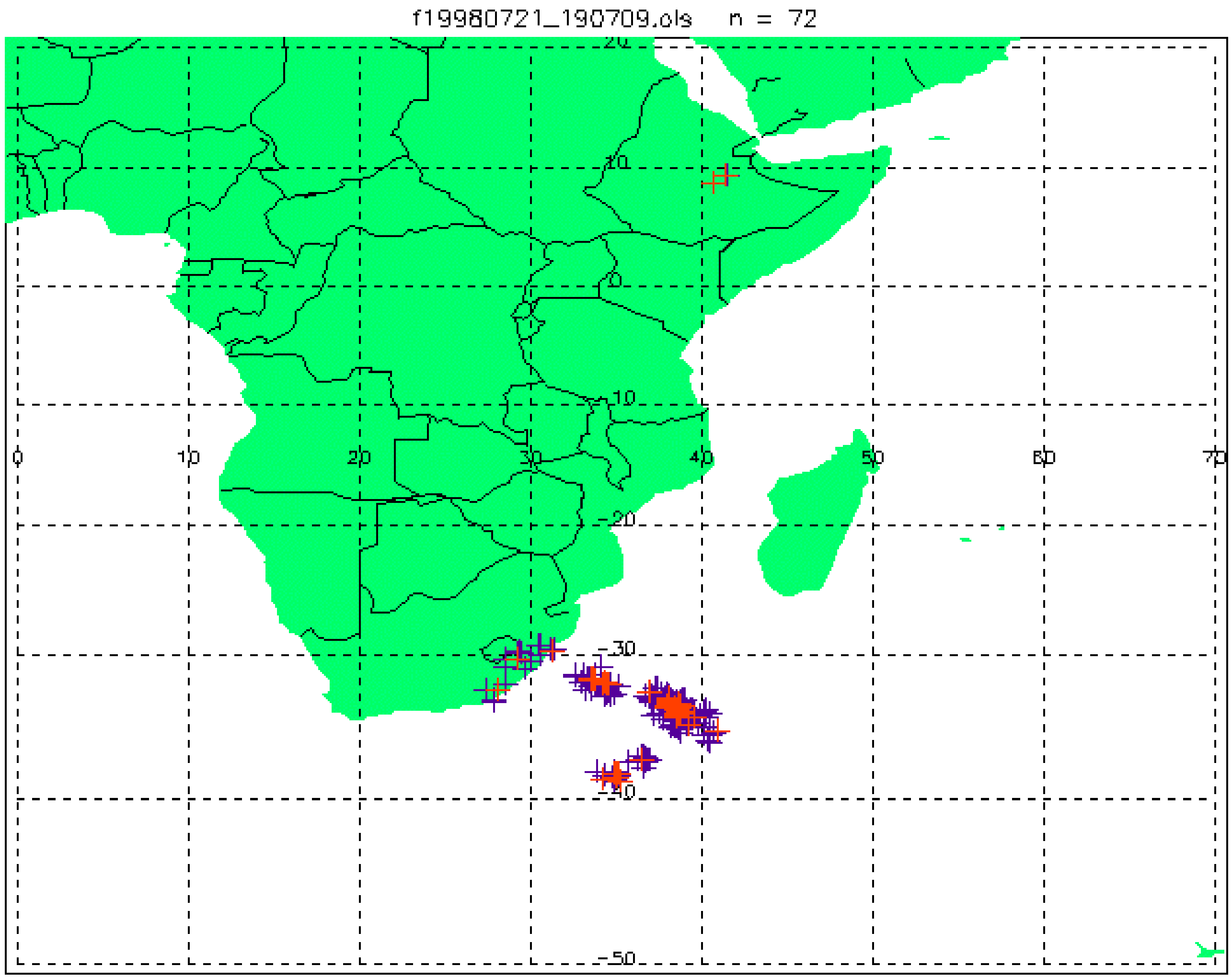


LLS events (red) after application of recurrence filter. t = 3 minutes; x = 50 km. Note that most of the events that look storm-related have been retained (clustering) while those events that are isolated in space (likely particle events) have been discarded. If we add in the LLS events that are accompanied by PDD triggers, we recover some previously discarded isolated LLS events (black) that are truly lightning events (e.g. in Mexico).



Example 2.

LLS events (purple) prior to application of recurrence filter. Notice the localized clustering of likely lightning events that are surrounded by an even distribution of particles events associated with the eastern-most extent of the South Atlantic Anomaly (SAA).



LLS events after application of recurrence and coincidence filters. t = 3 minutes; x = 100 km. Here we (a.) identify only those LLS events in coincidence with a PDD event (red), and then (b.) add all additional LLS events that are within x=100 km of events from (a) (purple). This results in keeping most of the likely lightning events while removing most of the suspected particle events. In summary, PDD coincidence requirements are most useful for identifying true LLS events that are (a.) isolated from major lightning centers, or (b.) occur in high energetic particle flux regions.

Multi-Sensor Observations

Multi-sensor (PDD/LLS/VHF) observations of CG and IC flashes are routinely collected by FORTE. Collectively, the three sensors provide a fairly complete picture of a lightning flash. The example on the right is of a CG flash and illustrates the majority of the phenomenology routinely seen by each of the sensors.

Comments:

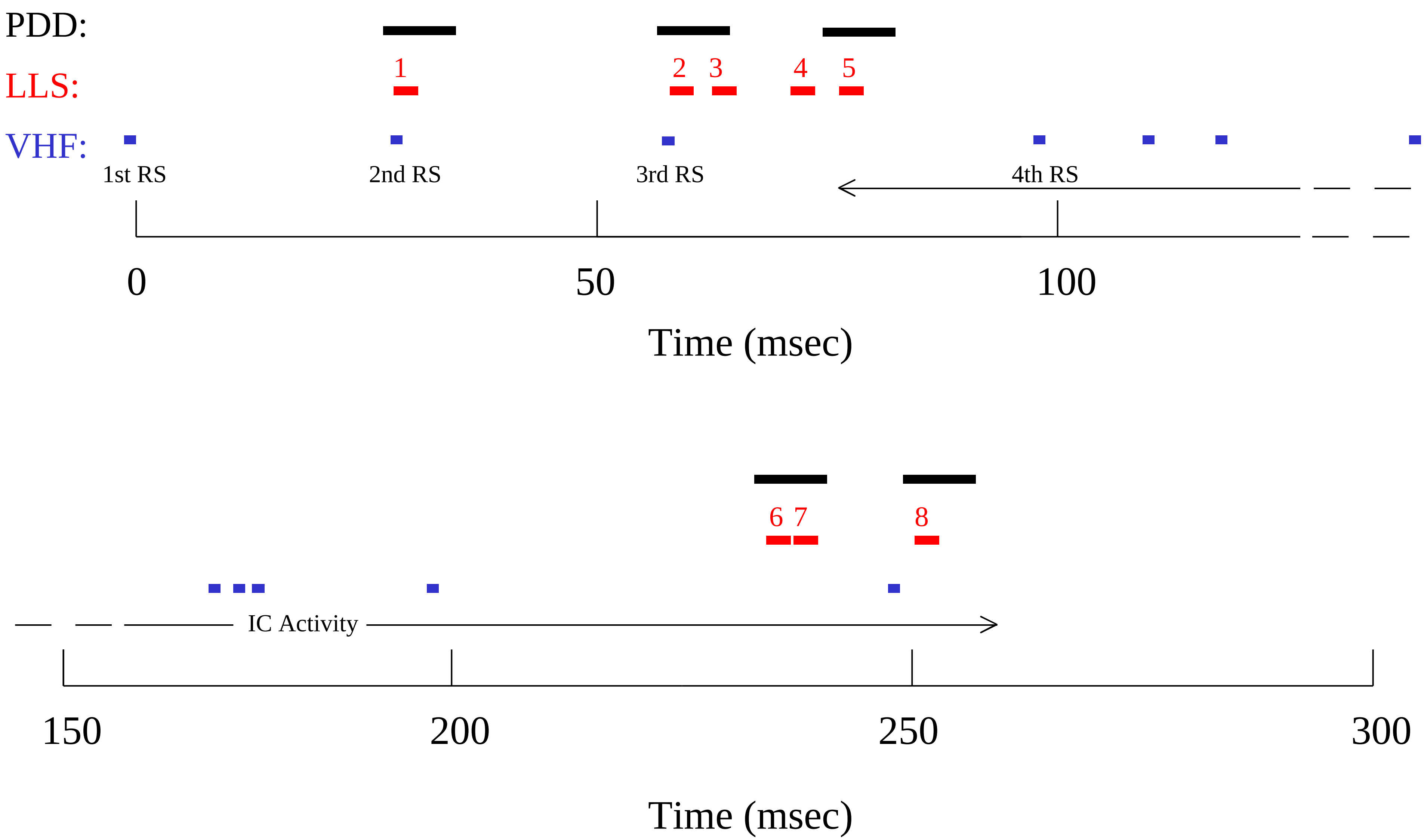
1.) The flash was isolated in time and space (as determined by LLS), and the VHF spectrograms all have the same amount of dispersion. These three facts assure us that all records are associated with the same flash.

2.) Every return stroke and in-cloud emission is not seen by every sensor. However, collectively, the three sensors give us a good interpretation of the event. Based on analysis of the illustrated spectrograms (Suszcynsky et al., JGR-Atmospheres in press [1999]), we interpret this flash as a 4-stroke -CG flash with significant in-cloud activity following the last return stroke.

3.) VHF records are usually coincident with optical return stroke signatures. The VHF is usually associated with the attachment processes, dart and stepped leaders, and the actual return stroke. The optical signature is typically associated with the in-cloud portion of the return stroke. Optical signatures of return stroke processes are generally narrow (< 1 ms width) and strong. There is a slight tendency for optical return stroke signatures to illuminate more pixels/event than optical IC activity. In the example, neither optical sensor (PDD or LLS) detected the initial return stroke; this is atypical.

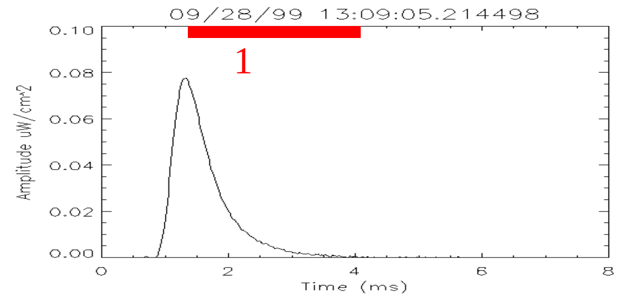
4.) VHF records are typically only in general coincidence with IC activity, as is seen in this example. Optical IC activity is generally characterized by broader (> 1 ms), weaker and more highly structured waveforms than those associated with return strokes.

CG Flash Example



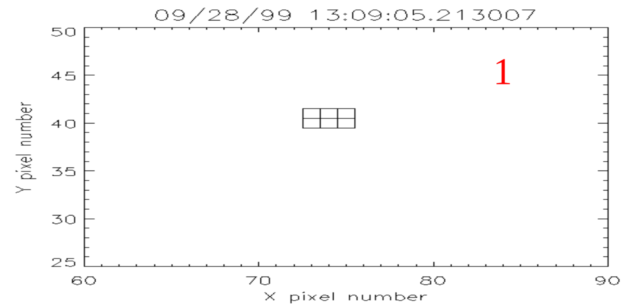
PDD

9/28/99 13:09:05.2074



LLS did
not trigger
PDD

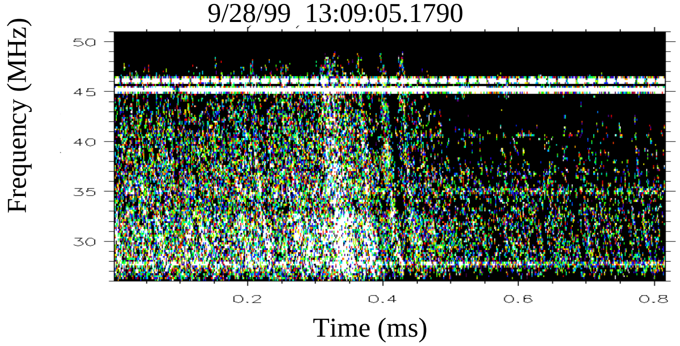
LLS



LLS did
not trigger

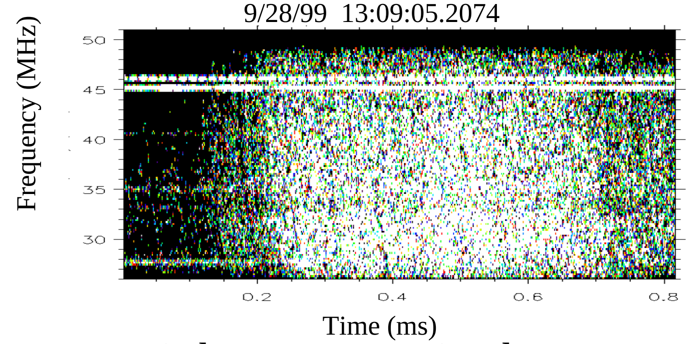
VHF

9/28/99 13:09:05.1790



Initial Return Stroke

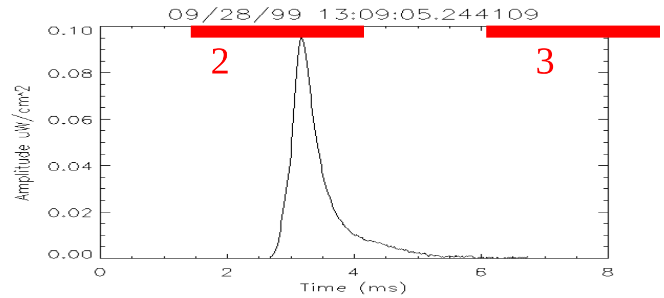
9/28/99 13:09:05.2074



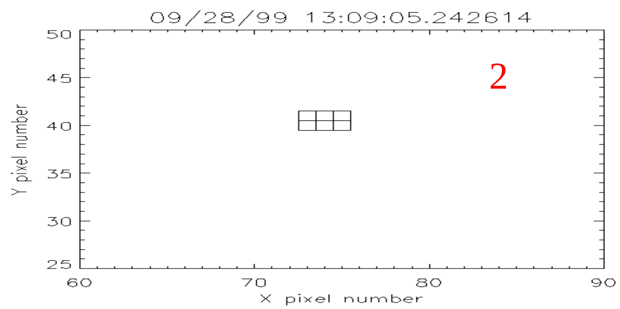
Subseq. Return Stroke

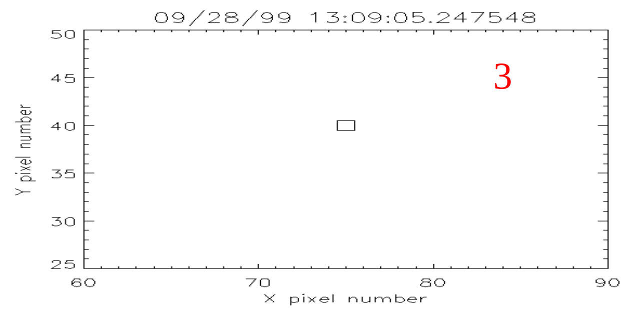
PDD

9/28/99 13:09:05.2074



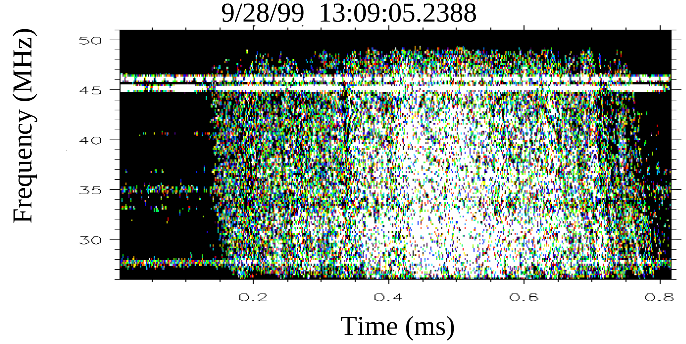
LLS





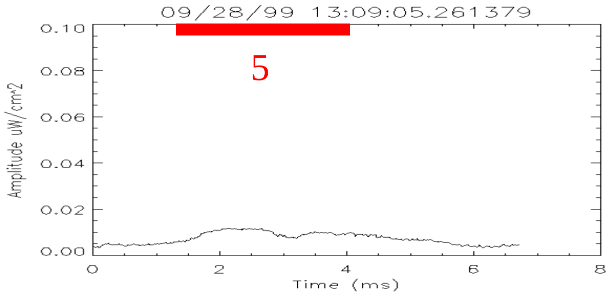
VHF

9/28/99 13:09:05.2388

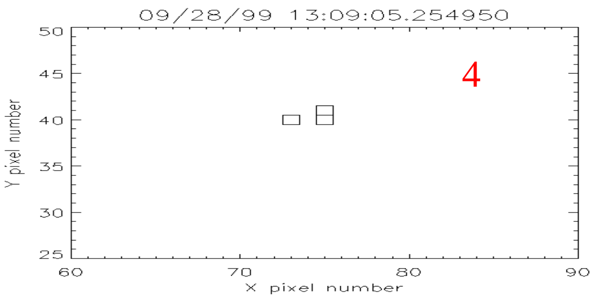


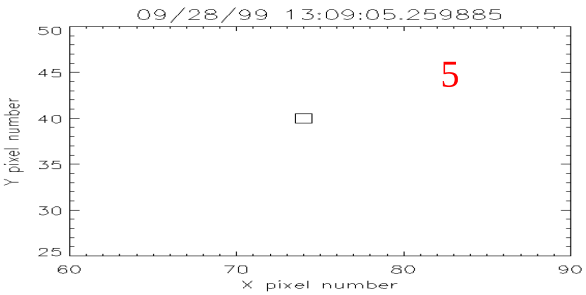
PDD

PDD was in dead time during LLS trigger



LLS





VHF

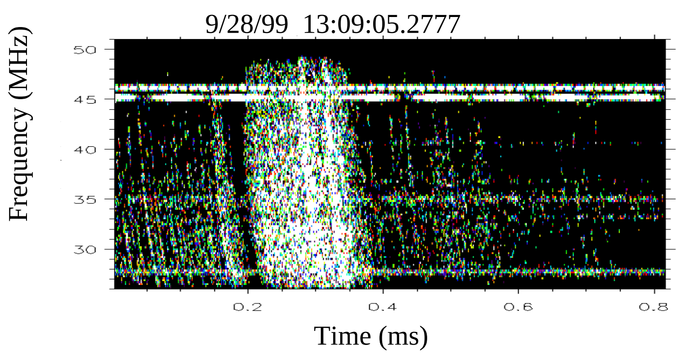
PDD

LLS did
not trigger
PDD

LLS

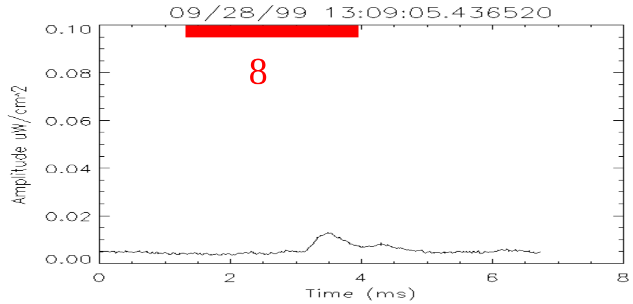
LLS did
not trigger

VHF

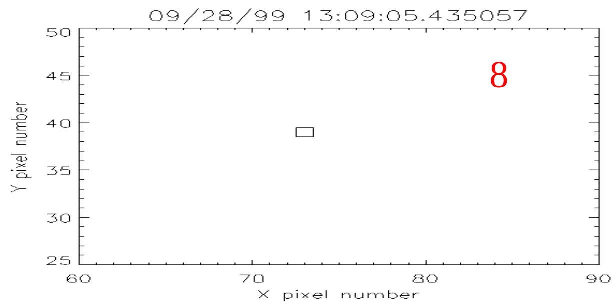


Subseq. Return Stroke

PDD


09/28/99 13:09:05.436520
8
Amplitude uW/cm^2
0.10
0.08
0.06
0.04
0.02
0.00
0
2
4
6
8
Time (ms)

LLS


09/28/99 13:09:05.435057
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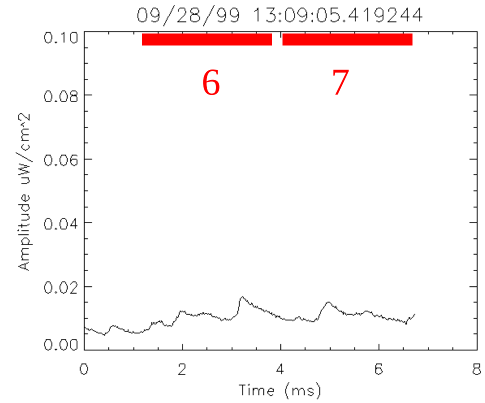
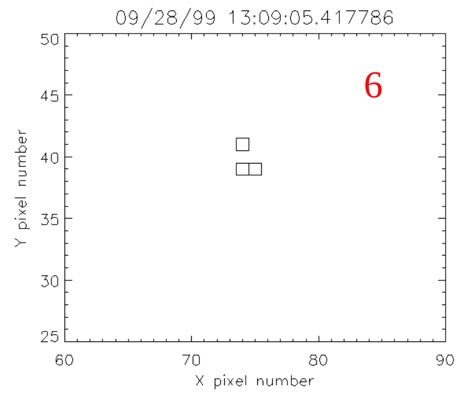
Y pixel number
50
45
40
35
30
25
60
70
80
90
X pixel number

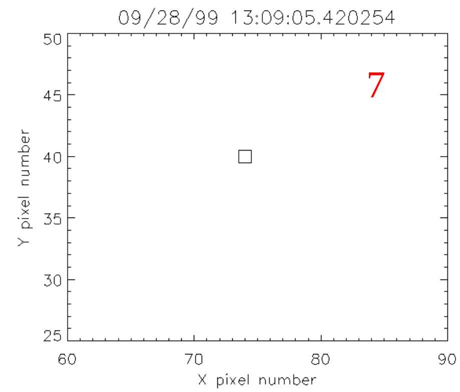
VHF

PDD

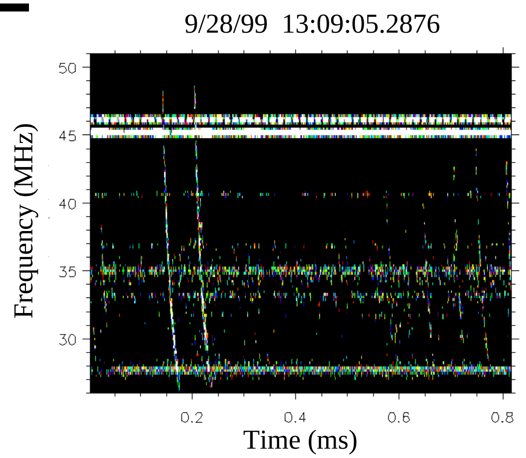


LLS





VHF



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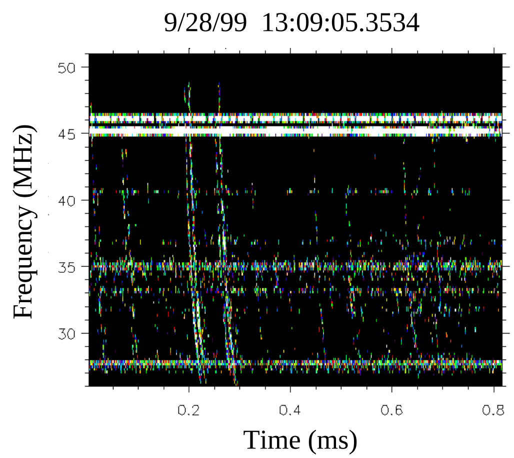

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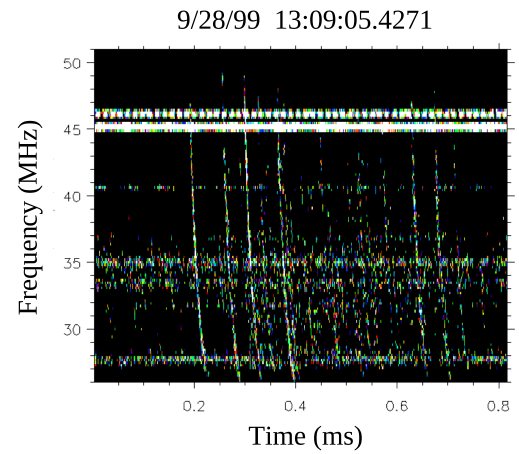

In-Cloud Activity……9 VHF triggers similar to these from t = 75 ms to 240 ms

Acknowledgements

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Related Papers at this Meeting

A. Davis, Optical Lightning Waveforms Observed from Space: An Information-Content Analysis Using Anomalous Diffusion Theory (A31A-08)

S. Davis et al, A Statistical Characterization of Lightning from Space Using the FORTE LLS (A31A-06)

T. Light et al., Monte-Carlo Simulations of Light Scattering by Clouds (A12B-05)